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Geology, Mineralization, and Hydrothermal Alteration and Relationships to Acidic and Metal-Bearing Surface Waters in the Palmetto Gulch Area, Southwestern Colorado

By

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Geology, Mineralization, and Hydrothermal Alteration in the Palmetto Gulch Area, Southwestern Colorado and Relationships to Acidic and Metal-Bearing Surface Waters

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ABSTRACT

The Palmetto Gulch area is affected by low pH and metal-bearing drainage from abandoned mines, and perhaps, from natural weathering around vein zones. To investigate these anthropogenic and potential natural sources of acidity and metals, we mapped the geology, veins, and hydrothermally altered areas; conducted mine dump leachate studies; and collected reconnaissance water quality data. Several small abandoned mines are present in the Palmetto Gulch area that produced small amounts of relatively high-grade silver ore from fault-controlled polymetallic vein deposits. These veins are hosted in lavas, breccias, and related volcaniclastic sediments that ponded within the 28 Ma San Juan-Uncompahgre caldera complex. These rock units generally have conformable contacts and have shallow dips to the northwest. Lava flows of pyroxene andesite, which host the Roy-Pray mine, are massive near their base and typically grade upward into tightly jointed rock with 2-15 cm joint spacing. In general, most hydrothermally altered rock within the Palmetto Gulch area is restricted to envelopes surrounding the mineralized veins and faults. Composite zones of vein-related alteration vary from about 50 to 80 m wide along the high ridgelines and narrow to less than 10 to 15 m beneath an elevation of about 5,462 m. Where unaffected by surficial oxidation, these altered zones contain as much as 7 to 10 volume percent finely-disseminated pyrite. The majority of rocks in the area were affected by regional and vein-related propylitic alteration. These greenish-colored rocks have alteration products consisting of chlorite, illite, and calcite; and feldspars are typically weakly altered. Most of these rocks have detectable amounts of calcite, while as much as 11 percent by weight was detected in samples collected during this study.

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Leach tests were performed on five dump samples from the Wyoming, Roy Pray, and the Palmetto mines. Values of pH from the leachate samples ranged from 3.07 to 3.85 for the 5 minute field-leach test with sulfate concentrations as much as 234 mg/L in the Roy Pray leachate. The Roy Pray dump sample produced the highest concentrations in aluminum (8,340 µg/L), copper (1,150 µg/L), iron (3,870 µg/L), manganese (8,740 µg/L), and zinc (15,500 µg/L). However, leachable lead concentrations were highest in samples from the Wyoming mine with 729 µg/L from the 5 minute leach and 8,300 µg/L in the 18 hour modified EPA leach. The leachate data indicates that all of the sampled dumps could potentially contribute to low pH and metal-rich runoff in this high alpine environment. However, the small to moderate size of these dumps (estimated less than 40,000 metric tons) should also be considered while assessing these potential contributions.

Water quality data for the Palmetto Gulch area is highly variable with pH values ranging from about 2.92 to 7.55, and specific conductance varying from 100 to 1,800 µs/cm. Mine discharge from the Roy Pray adit is associated with nearly the lowest pH (2.92) and highest conductivity (1,775 µs/cm) values in the Palmetto Gulch watershed. In contrast, water draining calcite-bearing propylitic-altered rock west of the Miner's Bank vein has pH values from 6.21 to 7.32 with specific conductivities of 110 to 242 µs/cm. Spring data from the easternmost tributary of Palmetto Gulch suggests that undisturbed vein and related alteration zones can produce acidic water with specific conductance at least as high as 300 µs/cm. Low angle bedding planes and contacts as well as low angle faults may be important pathways for near-surface spring waters in the Palmetto Gulch area.

INTRODUCTION

This report is part of an integrated study by the U.S. Geological Survey (USGS) to provide the geologic framework for the Palmetto Gulch area in the Henson Creek watershed, southwestern Colorado. This study was initiated at the request of the U.S. Bureau of Land Management (BLM) for the purpose of understanding potential sources of metals and low pH to the surrounding watershed. Studies conducted by the USGS included geologic mapping with specific detail on hydrothermal alteration, structural geology, and vein and disseminated mineral deposits. These studies, which aid in the understanding of non-mining and anthropogenic sources of metals and acidity within local surface waters, are critical for the interpretation of specific metal loads as identified by BLM stream tracer studies.

METHODS

Geologic mapping of lithologic units was based on the stratigraphy established by Lipman (1976a) in a regional map covering this area. Geologic contacts, veins, faults, and other features were located by standard field methodologies using an altimeter and a 1:24,000 topographic base map. The location of springs, seeps, mine openings such as adits and shafts, and prospects were similarly located, although many of these features were also verified by GPS. Thirty-five samples of variably altered rock and vein material were collected in the field. Twenty-five of these samples were analyzed for 40 elements by ICP-AES at a contract laboratory using the procedures of Briggs and Fey (1996). In addition, these samples were analyzed for carbonate carbon by coulometric titration and fluorine by ion selective electrode. Standard whole-rock X-ray analyses were conducted on the above 25 samples to confirm clay, sulfide, and primary mineralogies.

Five composite mine dump samples were collected from the Palmetto, Roy Pray, and Wyoming mines for leach analysis. Each mine dump was visually inspected for internal segregation of waste material; however, each of the dumps was generally homogenous in composition, and was thus sampled as an integral unit. A non-grid composite sample was collected from the five waste piles following the procedures outlined in Hageman and Briggs (2000). According to this method, 30 random sample increments from the upper 15 cm weathered surface of each dump were collected. All fragments > 4 cm were discarded and all increments were placed into a 2-gallon plastic bucket and mixed. The composite sample was then sieved to pass a 2 mm stainless steel screen and the < 2 mm fraction was saved for laboratory leach testing. Leach testing was conducted using both the five minute field-leach test and the 18 hour modified version of the EPA Method 1312 (SPLP) of Hageman and Briggs (2000). The dilution factor used during these experiments was 1 part rock to 20 parts water. Following extraction, the leachates from both experimental methods were filtered and an unfiltered aliquot of each sample was measured for pH and specific conductance (Hageman and Briggs, 2000). The leachates were analyzed by ICP-MS (Lamothe and others, 1999) at USGS laboratories in Denver, Colorado.

Reconnaissance water quality data were obtained at 41 sites during September of 1999. Field measurements at each site included discharge, specific conductance, pH, and water temperature. Dissolved oxygen was measured at eight sites. Methodologies for these procedures are discussed in Mast and others (2000).

GEOLOGY AND MINERALIZATION OF THE STUDY AREA

Regional Geology

The Palmetto Gulch study area is located within the western part of San Juan Volcanic field, which covered much of south-central Colorado during Oligocene and Miocene time (Steven, 1975). Volcanic activity, which was comprised of intermediate composition lava flows and pyroclastic eruptions, commenced about 35 Ma and continued to about 30 Ma (Lipman and others, 1970; Steven and Lipman, 1976). Between approximately 30 and 27 Ma, volcanism was dominated by extensive silicic ash-flow eruptions from concurrently forming calderas. These major pyroclastic sheets along with associated lavas and intrusions are thought to represent the tapping of high-level magmas during the waning stages of a major batholith beneath the San Juan volcanic field (Steven and Lipman, 1976; Plouff and Pakiser, 1972). Magmatism in the San Juan volcanic field shifted at about 25 Ma from largely intermediate composition, calc-alkaline volcanics to a bimodal assemblage of silicic alkali basalt and high-silica rhyolite, which continued intermittently to about 5 Ma.

The study area is situated along the north-central margin of the San Juan-Uncompahgre calderas (fig. 1), which simultaneously collapsed and erupted about 28 Ma (Steven and Lipman, 1976; Bove and others, 2001). This large composite volcanic structure formed within a cluster of older andesitic stratovolcanoes (Lipman and others, 1973) and has a prominent northeast to southwest elongation. This elongation may reflect structural control of the complex by a major zone of crustal weakness, such as faults of the Colorado Mineral belt, which project through this area (Tweto and Sims, 1963; Luedke and Burbank, 1968; Hon and others, 1986).

Collapse of the San Juan and Uncompahgre calderas was accompanied by thick accumulations of pyroclastic material (Eureka Member of the Sapinero Mesa Tuff) that ponded within the subsiding calderas. Insliding of debris from the steep caldera walls caused these calderas to expand well beyond their initial structural boundaries (Lipman, 1976b; Hon and others, 1986). The septum that initially divided the San Juan and Uncompahgre calderas also caved away at this time, causing a complete merging into the San Juan-Uncompahgre caldera complex. Volcanic activity continued in this area for several million years as indicated by the accumulation of dacitic to andesitic lavas and the eruption of the Crystal Lake tuff from the Silverton caldera (fig. 1). Collapse of the Silverton caldera at 27.6 Ma accompanied resurgence of the older San Juan-Uncompahgre calderas (Lipman and others, 1973; Bove and others, 2001). During this time period, several other regional ash-flow sheets, such as the Fish Canyon and Carpenter Ridge Tuffs (Tof on fig. 1)were erupted from calderas in the central San Juan volcanic field, and ponded within the Uncompahgre caldera.

Late bimodal igneous activity in the western San Juan Mountains is characterized by rocks of the 23 Ma Lake City caldera and by a linear trend of dacitic to rhyolitic intrusive rocks extending north of Lake City to Red Mountain Pass (fig. 1). Although most of the rocks along this trend are intrusive, the presence of 19 to 15 Ma extrusive rhyolite domes (rhyolite to dacite intrusions, fig. 1) and associated tuffs near the study area demonstrates that the paleo-ground surface at that time was near the stratigraphic horizon currently at about 5,726 m (13,000 ft) in elevation (Hon and others, 1986).

Volcanic Stratigraphy

The oldest rocks exposed within the Palmetto Gulch area are comprised of a thick sequence of biotite dacite lavas of the Burns Member of the Silverton Volcanics (plate 1; unit Tsb). These lavas were erupted along the margins of the San Juan-Uncompahgre calderas from multiple vent areas (Lipman and others, 1973). In the vicinity of the study area, the Burns Member lavas are at least 300 m thick; the unit generally dips gently to the north-northwest and gradually thins toward the north (Maher, 1983). In outcrop, the

Burns dacitic lavas are light to dark gray in color and contain phenocrysts of plagioclase, augite, and biotite, in a microcrystalline groundmass (Burbank and Luedke, 1969). This units forms low rounded hills and where modified by glaciation (i.e. Redcloud Gulch), forms steep, blocky cliffs.

The pyroxene andesite Member of the Silverton Volcanics (pyroxene andesite) crops out extensively within the study area. This unit usually lies conformably above the Burns Member, however, the Henson Member may sometimes lie beneath due to extensive interbedding of these units (plate 1). In the Palmetto Gulch area, the pyroxene andesite consists of four discreet lavas flows separated by zones of andesitic flow breccia (Maher, 1983). These flows are massive near their base and typically grade upward into tightly jointed rock (2-15 cm spacing (Maher, 1983). The tops of the flows commonly contain amygdules, which are comprised of chlorite, calcite, and chalcedony. These lavas generally show well-developed flow-banding, especially at the contact between flows and near the basal contact with the underlying Burns Member lavas (Maher, 1983). The pyroxene andesite is porphyritic and contains large euhedral lath-shaped or equant phenocrysts of plagioclase comprising up to 35 percent of the rock (Maher, 1983). Augite and hypersthene phenocrysts are typically equant grains and make up more than 10 percent of the rock. Some augite grains are as large as 1 cm across. Olivine phenocrysts are mostly fine-grained and altered to iddingsite; hornblende is characterized by euhedral laths as long as 1 cm. About 40 percent of the rock consists of an aphanitic groundmass made up mostly of plagioclase microlites and trace accessory minerals (Maher, 1983).

The Henson Member of the Silverton Volcanics for the most part conformably overlies the pyroxene andesite (plate 1). In the study area, the Henson Member mostly consists of light-green to gray tuffaceous sandstone (Maher, 1983; Hon and others, 1986). These sediments are mostly thin-bedded and consist of very fine-grained rock fragments and weathered phenocrysts. Grains are typically poorly sorted , angular to sub-rounded, and less than 0.1 mm across (Maher, 1983).

These units of the Silverton Volcanics are overlain by poorly welded distal flows of the 28 Ma Fish Canyon Tuff (plate 1) from the La Garita caldera in the central San Juan Mountains (Hon and others, 1986). This ash-flow sheet ponded within the San

Juan-Uncompahgre caldera, probably near the margins of the resurgent dome. The Fish Canyon Tuff is mostly gray to tan and contains about 30 percent phenocrysts of sanidine and plagioclase feldspar, quartz, biotite, and hornblende, and pyroxene (Maher, 1983). Much of this unit is highly altered and bleached where it is exposed in the study area (plate 1).

Although the Palmetto Gulch study area is located near the western margin of the 27.4 Ma Silverton caldera, no rocks related to that caldera are exposed in the immediate vicinity.

Intrusive Rocks

Intrusive rocks in the study area consist of a small stock at Engineer Mountain and several small rhyolite intrusions and dikes (plate 1). The Engineer Mountain stock is a porphyritic dacite (unit Tdp, plate 1) and contains distinctive sanidine megacrysts up to 4 cm long in a gray aphanitic groundmass. Other phenocrysts include plagioclase, resorbed quartz, and minor biotite. This intrusion is similar in age and composition to other 23 Ma dacite porphyry intrusions in the Red Mountain-Lake City area and in the vicinity of Red Mountain Pass, near Silverton (Hon and others, 1986; Bove and others, 2001). The dacitic intrusions at Lake City and near Silverton are spatially and genetically associated with important acid-sulfate alteration and related mineralization (Bove and others, 2001). The small rhyolite intrusions and dikes exposed in the study area are fine-grained felsites that are devoid of obvious phenocrysts. The dikes are typically less than 2 m wide and several have narrow glassy chilled margins. All the rhyolite dikes (unit Trd, plate 1), including the small plug near Redcloud Gulch (unit Tri, plate 1), are bleached and altered along their margins. These high-silica intrusions are localized along a N40E trending zone of rhyolites of similar age and composition that extend from just north of the study area, 5 km further to the southwest (Hon and others, 1986; Bove, USGS, field notes, 2001). Previous workers have demonstrated that these high-silica rhyolites were coeval and perhaps genetically associated with important vein mineralization in the western San Juan Mountains (Lipman and other, 1976; Maher, 1983; Hon and others, 1986; Bartos, 1993).

Structure of the Study Area

The Palmetto Gulch area lies along the structural margins of the San Juan-Uncompahgre and Silverton calderas (fig. 1). It also lies just outside or near the northwest margins of the prominent northeast-trending zone of tensional faults known as the Eureka graben (fig. 1); these structures formed along the crest of the resurgent dome of the San Juan-Uncompahgre calderas (Lipman and others, 1973; Lipman, 1976a). This zone is most structurally complex about 5 to 7 km to the southeast of the study area, where it intersects faults thought to be related to collapse of the Silverton caldera and the resurgent dome of the San Juan and Uncompahgre calderas (Steven and Lipman, 1976; Hon and others, 1983). The prominent faults of the Palmetto Gulch area generally trend about N30E, have no offset to very little normal displacement, and dip steeply to the east (Kelley, 1946; Lipman, 1976a; Maher, 1983)(plate 1). Many of these structures were filled with quartz veins and associated sulfides, and typically show evidence of post-mineralization faulting.

Geology of Mineral Deposits in the Palmetto Gulch Area

The Palmetto Gulch area hosts a series of veins that filled structures related to the northeast-trending Eureka graben (plate 1). These veins, which range from 0.1 to 5 m wide, contain silver and base-metal ores that were commonly brecciated by post-ore faulting and cemented by barren quartz. Approximately $1,000,000 in ore (value at time of production) was mined between 1880 and 1920 from the Frank Hough ($600,000), Polar Star ($250,000), Palmetto ($150,000), and Wyoming ($50,000?) mines)(Kelley, 1946; Hon and others, 1986), all of which are located in or adjacent to the Palmetto Gulch drainage (plate 1).

The Frank Hough mine was the only mine in the Palmetto Gulch area to make a substantial profit, producing about 350,000 ounces of silver, 1,600 ounces of gold, and 2,500 ounces of copper (Kelley, 1946; Hon and others, 1986). Ore minerals were localized along a northeast-trending fault that cuts tuffaceous sandstone of the Henson Member (plate 1). Mine workings are reported to extend over a 90 m vertical range following an ore zone that widened from about 5 to 10 m with increasing depth (Ransome, 1901; Hon and others, 1986). The width of the ore zone greatly exceeded that of the fault, and ore descriptions indicate an origin by replacement of the surrounding wall rock (Ransome, 1901; Kelley, 1946). Ore material on the dump is comprised of a fine-granular aggregate of quartz intergrown with chalcopyrite, pyrite, tetrahedrite, minor galena, and rare hessite (Ag_2Te)(Kelley, 1946; Hon and others, 1986); chalcocite reportedly occurs as a secondary mineral (Ransome, 1901; Hon and others, 1986). A sample of ore material collected from the mine dump contained 1,000 ppm silver, 2,000 ppm lead, > 90,000 ppm copper and arsenic, 1,500 ppm zinc, and 1,000 ppm bismuth (no. 722, Fischer and others, 1968). Propylitic-altered country rock sampled near the mine (table 1, this study; sample no. 721, Fischer and others, 1968) has elevated copper content (120 to 500 ppm) but does not display anomalous amounts of other elements detected in the above-mentioned dump sample. The very-high copper and low lead and zinc values from this mine are not typical of polymetallic veins of the western San Juan Mountains (Hon and others, 1986).

The Polar Star, Palmetto, and Wyoming mines produced ores that are much more typical of the polymetallic deposits in the region. These deposits were localized along 0.1 to 5 m wide quartz-filled fissures hosted in the pyroxene andesite and Burns Members of the Silverton Volcanics (plate 1). The best ores were reportedly associated with zones of flow breccias between individual flow units (Kelley, 1946). The upper portions of these veins were especially rich in silver ores containing ruby silver and acanthite in a vuggy quartz matrix (Ransome, 1901; Kelley, 1946; Hon and others, 1986). Base-metal sulfides of galena, sphalerite, chalcopyrite, and tetrahedrite-tennantite were relatively sparse in this upper zone, but became increasingly more abundant at depths greater than 90 m beneath the ground surface (Ransome, 1901; Hon and others, 1986). Silver diminished in the lower workings of these mines (< 12 ounces/ton), which contained ores rich in pyrite and quartz (Ransome, 1901).

The Polar Star mine (plate 1) was first opened in 1880 and produced about 1,700 tons of ore through 1892 (Kelley, 1946). The ore, which was hand picked, averaged 0.12 ounces of gold and 72 ounces of silver per ton (Kelley, 1946). The Palmetto Mine, which was located along the northern extension of the same vein as the Polar Star (Miner's Bank Vein, plate 1), operated from 1880 until 1891; early production figures from this mine are not well documented. However, unpublished records from exploration work in the late 1960's estimate ore reserves of about 18,000 tons averaging 13 ounces of silver per ton (Hassler and Ebbley, 1969). A composite dump sample from the Roy Pray mine (plate 1), also located on the Miner's Bank vein, contains 24 ppm silver, 420 ppm arsenic, 10 ppm cadmium, 280 ppm copper, 2,300 ppm lead, and 1,700 ppm zinc (table 2). Composite samples from two mine dumps from the Palmetto mine averaged 70 ppm silver, 930 ppm arsenic, <2 ppm cadmium, 70 ppm copper, 190 ppm molybdenum, 970 ppm lead, and 250 ppm zinc (table 2). A grab sample of ore material from the shaft dump (sample PG9; plate 1) contains 530 ppm silver, 260 ppm arsenic, 210 ppm copper, 316 ppm molybdenum, 3,820 ppm lead, and 4,320 ppm zinc (table 1). This sample contained major amounts of pyrite, galena, sphalerite, and trace? tetrahedrite (table 3).

The Wyoming Mine, which exploited the Emperor Wilhelm vein (plate 1), operated intermittently from 1901 through 1920 (Maher, 1983). Total production was about 150 tons of hand sorted ore averaging 1.1 ounces gold, 190 ounces silver, 9 percent lead, 1 to 1.5 percent bismuth, 10 to 15 percent zinc, and trace amounts of copper (Kelley, 1946; Maher, 1983). Composite samples from the upper and lower mine dumps (plate 1; PG01WUD, PG01WLD) average 155 ppm silver, 110 ppm arsenic, 15 ppm cadmium, 45 ppm copper, 2,160 ppm lead, and 2,740 ppm zinc (table 2). In contrast, a sample of hand-picked ore material contains 870 ppm silver, 140 ppm arsenic, 300 ppm cadmium, 12,600 ppm copper, 31,000 ppm lead, and 57,700 ppm zinc (table 1; sample PG15). Ore minerals identified in this sample were galena, sphalerite, chalcopyrite, and minor pyrite (table 3).

The Hoffman, Flower of San Juan, and several unnamed quartz veins (plate 1) are subparallel to the Miner's Bank and Emperor Wilhelm veins. Outcrops of these veins are generally characterized by banded or cockscomb quartz with fine-grained pyrite, sericite, and rare base-metal sulfides. Only a few small adits, shallow shafts, and prospect pits were observed along these structures. Waste dumps associated with these exploits are generally less than about 30 m^2 and rarely more than 1m in depth. Vein and altered material from these structures show anomalous silver (≤ 150 ppm), arsenic (≤ 450 ppm), copper (≤ 350 ppm), and lead (≤ 2,600 ppm)(table 1). Reports by Kelley (1946) indicate that 16 tons of silver-rich ore were shipped from small open cuts on and around the

Hoffman vein (plate 1). No other production records have been found for workings along these veins in the Palmetto Gulch area.

Alteration Assemblages

In general, most hydrothermally altered rock within the Palmetto Gulch area is restricted to envelopes surrounding the mineralized veins and faults (plate 1). One major exception, however, is an elongate zone (120 m by 1,300 m) of highly bleached, weak sericitic-altered (WSP) rock that extends along the Engineer Mountain divide, mostly superimposed on Fish Canyon Tuff. Nearly all the rocks in the study area were affected by low-grade regional metamorphism or propylitization due to thermal events related to the San Juan-Uncompahgre and later Silverton calderas. The timing of this alteration event is roughly constrained to about 28.2-27.5 Ma—the ages of these respective calderas—and preceding most ore mineralization by 5-15 Ma (Lipman and others, 1973; Bove and others, 2001). Rocks of the regional propylitic mineral assemblage are green to light green and contain varying amounts of chlorite, calcite, and illite, in the presence of metastable to stable primary feldspar crystals; mafic phenocrysts within these lavas are characteristically altered to pea-green mixtures of fine-grained illite and chlorite, with tiny clusters of magnetite and hematite. In contrast, zones of hydrothermal propylitic-altered rock (plate 1) generally contain small amounts of fine-grained pyrite within the rock groundmass and along fractures. These rocks also may contain less calcite than their regional counterparts, and plagioclase grains are typically more altered. The hydrothermal propylitic assemblage formed contemporaneously with vein activity and post-dates the regional propylitic assemblage. Calculated calcite abundances as determined from analytical data, range from 3 to 11 weight percent (6 percent average) in both regional and hydrothermal propylitic altered samples (table 1).

Composite zones of vein-related alteration vary from about 50 to 80 m wide along the high ridgelines (plate 1; fig. p1 and fig. p2) and narrow to less than 10 to 15 m beneath an elevation of about 5,462 m (12,400 ft)(plate 1; fig. p3 and fig. p4). The vein alteration assemblage changes outward from a quartz-sericite pyrite (QSP) zone nearest the veins (3-15 m wide), into bleached and softer, weak-sericite-altered rocks (3-15 m wide), and finally into a marginal hydrothermal propylitic zone (up to 25 m wide). X-ray diffraction data (table 3) indicates that the inner QSP assemblage is highly silicified, contains finely disseminated pyrite or jarosite, and minor to trace amounts of pyrophyllite and dickite. The weak sericite assemblage contains abundant sericite after plagioclase and mafic grains, although potassium feldspar minerals are stable to weakly altered. These rocks are generally not silicified, and where unoxidized contain as much as 7 to 10 volume percent finely-disseminated pyrite. Minor to trace amounts of kaolinite are only rarely present within these weakly sericitic-altered rocks (table 3). However, earlier studies of the Polar Star mine (along the southern extension of the Miner's Bank vein) have shown a bleached zone adjacent to the vein containing abundant kaolinite, diaspore, and about 7 weight percent disseminated pyrite (Ransome, 1901). These argillized and highly pyritic zones extend to depths of at least 220 m below the surface (Ransome, 1901).

The elongate zone of weak sericitic-altered rock (WSP) near the Engineer Pass divide (plate 1(blue dot pattern); fig. p5) is not related to an exposed vein structure. However, these rocks are present along the margins of the mineralized and highly altered Engineer breccia pipe complex (Maher, 1983; Hon and others, 1986), located in the unmapped area northwest of Palmetto Gulch (plate 1). This bleached zone of WSP-altered rocks is nearly identical in mineralogy and overall character to the WSP envelopes around the polymetallic veins.

A small zone of highly silicified, acid-sulfate-altered rock is exposed immediately north of Engineer Mountain (plate 1; red hachures). These rocks are characterized by abundant fine-grained quartz, dickite, and minor to trace amounts of pyrophyllite. Disseminated pyrite is mostly oxidized within this zone, which is cut by a number of 1 to 5 cm quartz-pyrite veins. This small alteration zone and the wider vein alteration envelopes at the present day ridgelines likely mark a near-surface environment where high level acid-sulfate fluids were dominant at the time of hydrothermal alteration.

DUMP LEACHATE STUDIES

Leach tests were performed on five dump samples from the Wyoming, Roy Pray, and the Palmetto mines (plate 1; fig. p6 and fig. p7; table 4). Due to private land status, the sulfide-rich Hough mine dump was not sampled. All of the sampled dumps were of small to moderate size ranging from an estimated 10,000 to 40,000 metric tons. Major and minor mineralogy of the < 2 mm composite dump material as determined by X-ray diffraction study include quartz, sericite, jarosite (possibly Pb-bearing), goethite, gypsum, sanidine, and sphalerite; trace amounts of alunogen ($Al_2(SO_4)_3 \cdot 17H_2O$), cerrussite ($PbCO_3$), and coquimbite ($Fe_2(SO_4)_3 \cdot 9H_2O$) were also identified while x-ray amorphous iron hydroxides and unidentified copper oxide minerals are also present. Although metal-bearing soluble salts are also likely present on these dumps (Desborough and others, 1999), their abundances are generally too low to be detected by X-ray diffraction of the composite samples.

Values of pH from the leachate samples ranged from 3.07 to 3.85 for the 5 minute field-leach test. Leachable sulfate concentrations[4] were highest in the sample from the Roy Pray dump (234 mg/L), while the Wyoming dumps generated 10-30 mg/L sulfate. The Roy Pray dump (plate 1) produced the highest concentrations in aluminum (8,340 µg/L), copper (1,150 µg/L), iron (3,870 µg/L), manganese (8,740 µg/L), and zinc (15,500 µg/L). Concentrations of arsenic, cadmium, and lead in this sample, although elevated, were less than 100 µg/L. Abundances of aluminum, copper, iron, and manganese were considerably lower in the other four dump leachates, while zinc concentrations ranged from 120 to 1,800 µg/L. Leachable lead concentrations were relatively high in samples from the Wyoming mine with 730 µg/L from the 5 minute leach to 8,330 µg/L in the 18 hour modified EPA leach. These anomalously high concentrations are notable and would not be predicted as the bulk lead composition in all mine dump samples was generally similar (table 2). The high concentrations of lead within the Wyoming dump samples probably reflects the presence of cerussite ($PbCO_3$), which typically forms by oxidation of galena in the upper levels of polymetallic veins in this area (Ransome, 1901; Hon and others, 1986). Galena, which is much less soluble than cerussite, would generally not yield much lead to the leach solutions (Desborough and others, 1999). The leachate data indicate that all of the sampled dumps could potentially contribute to low pH and metal-rich runoff in this high alpine environment. These tailings are probably the most susceptible to leaching during summer storm events, which rapidly dissolve metal-rich salts that form within the dump piles (Plumlee and others, 1999). Historical production

[4] All analyzed results represent total concentrations that could be leached from the material

records and reconnaissance data from the Hough mine (see above discussion) suggest that the associated tailings pile could also be a potential source of low pH water and leachable metals, especially copper.

STREAM SEDIMENT SAMPLES

Stream sediment samples taken from drainages in the Palmetto Gulch area have anomalous amounts of the base-metal elements copper, zinc, and lead, as well arsenic (see table 2 in Hon and others, 1986). As shown on plate 1, copper abundances within these sediments range from 1,000 to 3,500 ppm along the tributary below the Hough mine, whereas, 750 to 2,200 ppm zinc is present in most of these drainages. It is likely that these high metal concentrations are related to fluvial tailings and to colloidal coatings within the bed sediments (Church and others, 1997). Accumulations of fluvial tailings within the stream beds are most likely in stream reaches with low gradients such as directly below the Hough and Roy-Pray mines (plate 1). Metals from these sediments and colloidal coatings could be a potential source of dissolved metals, especially during low pH summer storm events (Smith and Huyck, 1999). Further study of these metal-bearing sediments would be warranted if mine dump reclamation was to be undertaken in the Palmetto Gulch area.

DISCUSSION AND CONCLUSIONS

Water Quality Data and Relationship to Geology and Mineralization

Reconnaissance water quality data for the Palmetto Gulch area (fig. 2, table 5) is highly variable with pH values ranging from about 3.21 to 7.55, and specific conductance varying from 110 to 1,775 µs/cm (plate 1). Mine discharge from the Roy-Pray adit is associated with the nearly lowest pH and highest conductivity values in the Palmetto Gulch watershed (pH=3.34; conductivity =1,775 µs/cm; WPALM 15; table 5). Unpublished geochemical data from this same site shows high concentrations of dissolved aluminum (16.3 mg/L), manganese (28 mg/L), zinc (8 mg/L), and sulfate (980 mg/L)(B. Hite, BLM, 2002, written commun.). Mine discharge from the Hough mine also has low pH (3.72) and high conductivity (1,690 µs/cm; WPalm 1, table 5). Based on dump geochemistry and stream sediment data, these highly conductive waters are assumed to be high in dissolved metals. A tributary below the Wyoming mine also has low pH (3.96; WPalm 32, fig. 2, table 5)) and moderately elevated conductivity (360), while the mine pool from a nearby adit on the Emperor Wilhelm vein (plate 1) has a pH of 4.03 and conductivity of 580 µs/cm (Wpalm 33, fig. 2, table 5). In contrast to these data, water draining regional propylitic-altered rock west of the Miner's Bank vein has pH values from 6.21 to 7.32 with specific conductivities of 110 to 242 µs/cm (plate 1). Unpublished geochemical data from a sample in the upper reaches of Palmetto Gulch, where it drains propylitic-altered rock, shows measurable alkalinity, and contains 240 mg/L sulfate, and 3 µg/L zinc (B. Hite, BLM, 2002, written commun.). As shown on plate 1, pH decreases while conductivity increases downstream along this stream segment due to the influence of adjacent mines or prospects. A spring draining along the projection of the Miner's Bank vein (plate 1) had a pH of 3.29 and conductivity of 1,120 µs/cm (sample Wpalm26, table 5).

It is notable that pH is relatively high (6.63) at a tributary site (Wpalm 7, table 5) just 250 meters below the draining Hough mine. These high pH values are probably related to interaction with hydrothermal and regional propylitic-altered rock that contains abundant calcite (plate 1; table 1). Conductivity data along this stream segment to a point above the Palmetto mine (plate 1) ranges from 260 to 280 µs/cm Wpalm7 and 8, table 5). However, reconnaissance data indicates that this stream segment is susceptible to sharp drops in pH during summer storm events. During one such event in late summer of 2001 (at a point just above the Palmetto mine, plate 1), pH dropped from 6.90 to 3.90, while specific conductivity increased from 280 to 380 µs/cm. These changes appear to have been influenced by runoff over the Hough mine dump, about 600 m upstream. It is also possible that fluvial tailings and colloidal-adsorbed metals within these bed sediments (below the Hough site) could also be remobilized during these low pH events.

The easternmost tributary of Palmetto Gulch drains the Hoffman and a parallel vein (plate 1). Two small springs in the headwaters of this tributary drain an 80 m-wide alteration zone enveloping these mineralized veins (plate 1). These springs have pH values of 4.16 and 4.43 with specific conductivities of 220 and 240 µs/cm (Wpalm36 and 38). Although the westernmost of these springs (Wpalm36) may be impacted by the small prospects just above (see section on geology of mineral deposits), the eastern spring appears to be unaffected by mining or exploration activity (Wpalm38). A small spring located < 100 m downstream of rock sample site PG17 (plate 1, fig. p9; sample Wpalm40, table 5) emanates along trend of an unnamed mineralized vein, about 50 m east of the Hoffman structure. This spring had a measured pH of 4.01 and a specific conductivity of 535 µs/cm (Wpalm40, table 5). A small dry prospect about 3 m wide by 3 m deep is located along this same vein structure, about 130 m upslope of the spring (plate 1, figure p8). In addition, a small exploratory adit (plate 1) with a 3 m by 2 m-wide dump is situated about 80 m down slope of the spring site. Near the adit, the quartz-filled vein contains about 1 percent fine-grained pyrite, sericite, and a trace of chalcopyrite. Although these small prospects do not appear to have an impact on the spring water, such influence cannot be entirely ruled out. Unlike the Miner's Bank and Emperor Wilhelm veins to the west, there is no field or historical indication of significant underground workings along these eastern-most vein structures. Water in the tributary just below the spring and small adit, had a pH of 4.15 and conductivity of 328 µs/cm (Wpalm41, table 5). The streambed within this reach is coated with a white precipitate, possibly due to mixing of low and high pH waters during spring runoff. A stream sediment sample taken along this tributary, immediately above the junction with upper Palmetto Gulch (plate 1), contains 430 ppm copper, 115 ppm lead, 2,170 ppm zinc, and 300 ppm arsenic (no. 2339; Weiland and others, 1980). This data indicates that some of these more soluble constituents could also be elevated within the stream water due to interaction with mineralized vein material exposed along this drainage. A spring along the Flower of San Juan vein, just above the mainstem of Palmetto Gulch shows the natural influence of this mineralized vein structure (plate 1, fig. p3). This small spring had a pH of 3.92 and a conductivity of 282 µs/cm.

Several small springs discharge at the contact between the Burns and the overlying pyroxene andesite lavas in the vicinity of the Roy Pray adit (plate 1). These spring waters were clear with pH values ranging from 5.45 to 6.57 and conductivities from 120 to 130 µs/cm (samples Wpalm 11 and 12, table 5; S. Paschke, U.S. Geological Survey, oral commun., 2002). In addition, water seeping along a highly jointed and fractured zone near the Roy-Pray portal was also relatively clear and had pH values ranging from 5.60 to 6.00 (S. Paschke, U.S. Geological Survey, oral commun., 2002; Stover, 2002). Studies by Stover (2002) suggest that these highly fractured and jointed rocks near the Roy Pray portal represent the upper 30 m of broken rock that underlies the ground surface in this area. Another possible for this densely fractured and jointed zone, however, could be a lithologic change within the pyroxene andesite to flows characterized by tightly-spaced, sheeted jointing (see above section on volcanic stratigraphy; Maher, 1983). According to Stover (2002), the dilute water observed along this fractured zone may be linked to water flowing at the ground surface within the watershed.

The discharge of springs at the Burns and pyroxene andesite contact, below the Roy Pray mine (plate 1), indicates that low angle bedding planes and contacts may also act as pathways for near-surface waters. In addition, several springs in the western part of the study area discharge in bedrock along low angle foliation or bedding planes (plate 1). The possible control of such low-angle structures on hydraulic conductivity is also suggested by previous underground mapping studies of the Roy Pray mine, which document substantial amounts of water discharging along a low-angle fault (<30 degrees) along the Miner's Bank drift, several hundred meters south of the Roy Pray cross-cut (Hassler and Ebbley, 1969). More definitive resolution of these observations and theories could be resolved by detailed fracture-flow and hydrologic studies in this area. Such studies would be warranted if plugging of the Roy Pray adit is considered as leakage could occur along many springs in the area or along the many mine openings on the Miner's Bank structure (plate 1).

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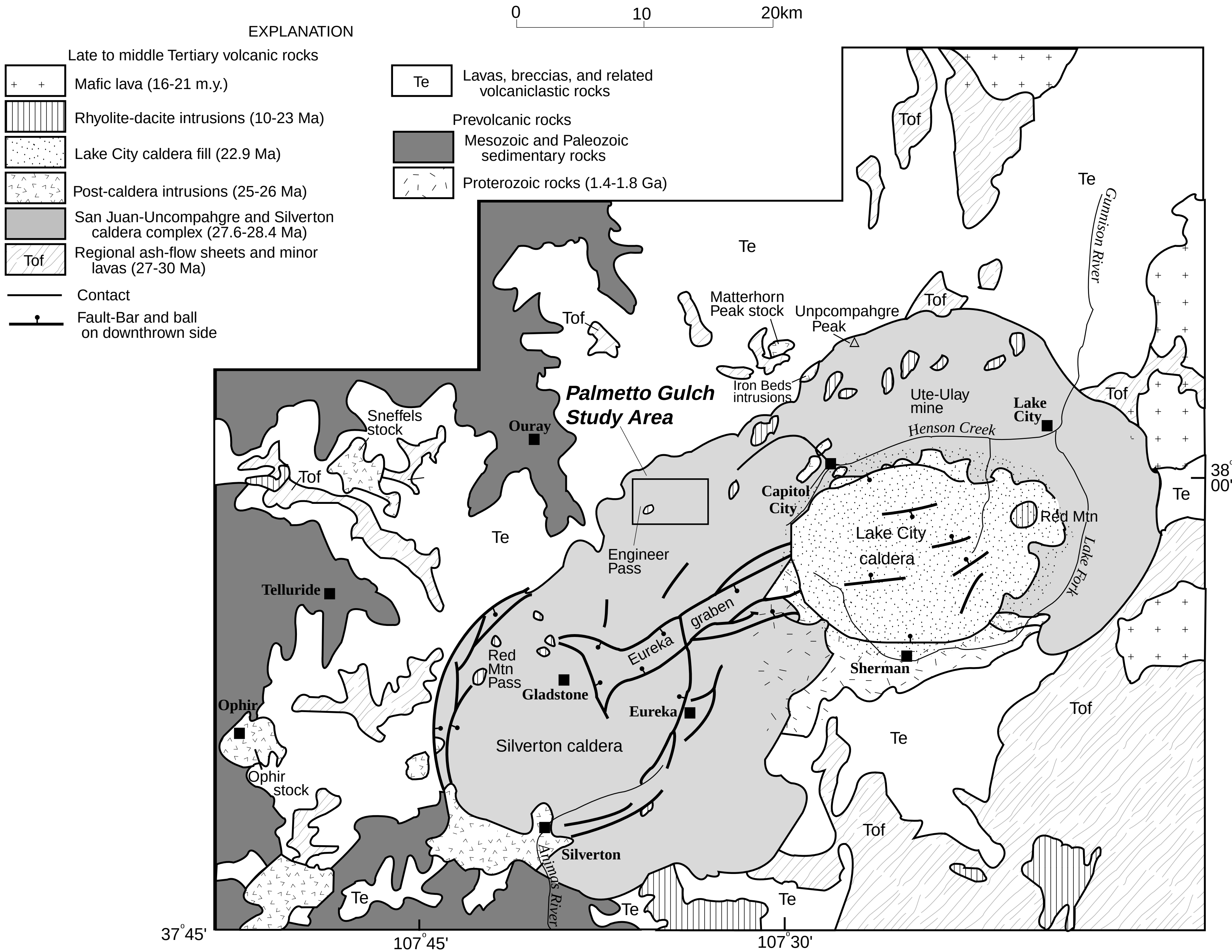

Figure 1. Generalized geologic map of the western San Juan Mountains area, showing the general locality of the Palmetto Gulch area. Geology modified from Lipman and others (1986) and Bove and others (2001)

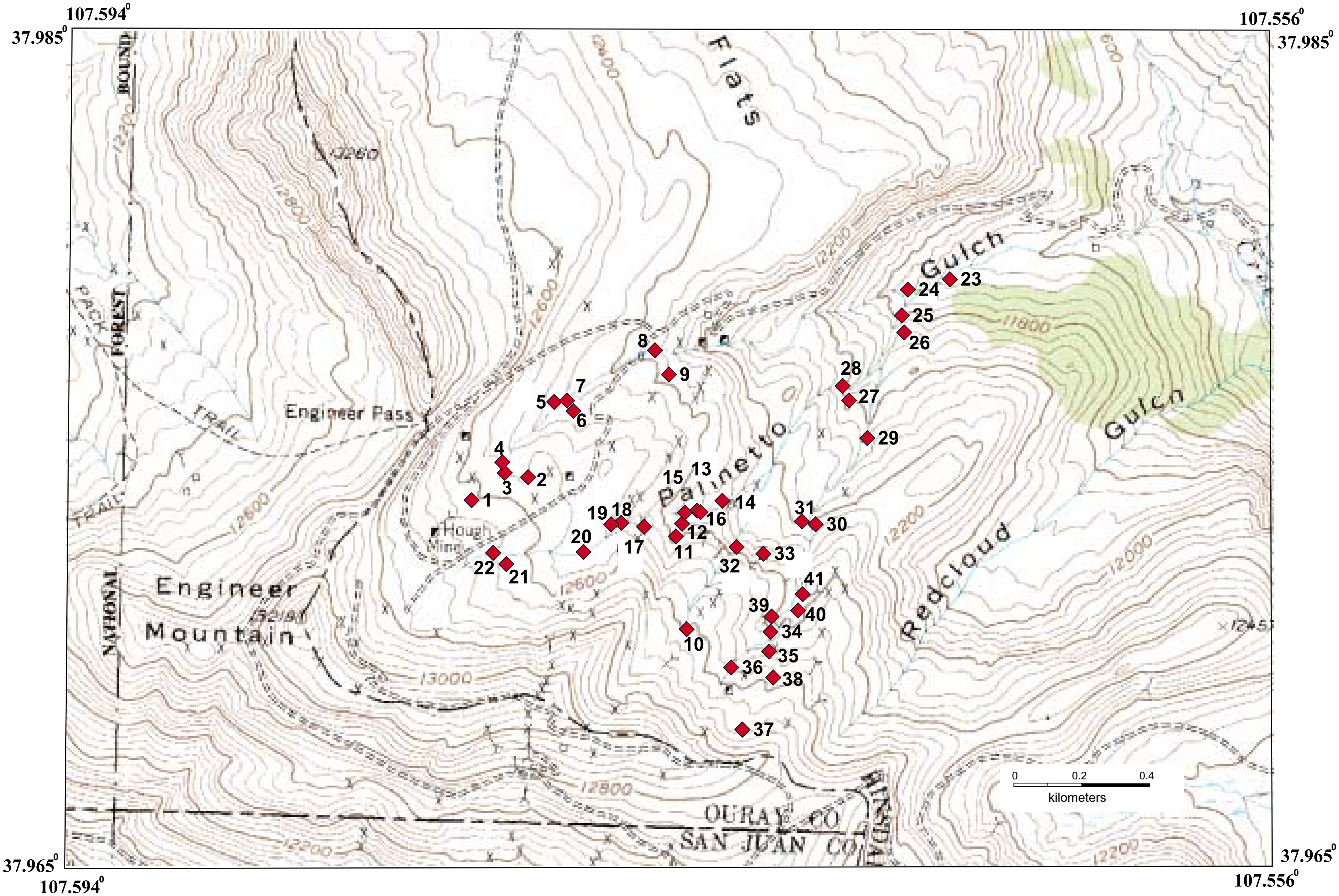

Figure 2. Location map showing reconnaissance water quaility data sites. Data is presented in table 5.

Table 1. Geochemistry of rocks, vein, and dump material from the Palmetto Gulch area. Weight percent calcite was calculated from percent carbonate carbon.

Field No.	Sample Description	Calcite %	Carbonate C %	F %	AL %	CA %	FE %
PG1	bleached and weak sericitic-altered Tf	0	<0.003	735	6.39	0.05	1.13
PG4a	very weakly altered rhyolite dike	0	<0.003	363	5.91	0.17	0.43
PG4b	sericitic altered margins of rhyolite dike, no sanidine	0	<0.003	364	6.54	0.13	0.52
PG5	WSP-altered zone adjacent to rhyolite dike on Hoffman vein; k-feldspar stable	0	<0.003	925	3.93	0.05	2.11
PG6	bleached and weak sericitic-altered Tf	0	<0.003	407	6.98	0.06	0.28
PG8	grab dump material from lower Palmetto adit	0	<0.003	285	2.55	0.03	4.23
PG9	grab dump material from lower Palmetto shaft	0	<0.003	212	1.41	0.05	3.5
PG10	highly altered and silicified Tf with dickite, minor pyrophyllite, and svanbergite cut by qtz veins	0	<0.003	1310	3.14	0.03	0.31
PG11	strongly propylitized Tsh, major calcite, no stable feldspar	11.11	1.33	1100	7.54	4.52	5.34
PG12	green propyltized Tsh, stable plagioclase, metastable biotite, minor calcite	3.07	0.37	654	5.29	1.41	1.96
PG13a	35 ft wide QSP zone adjacent veinTap	0	<0.003	990	2.66	0.05	1.62
PG13b	15-20 ft vein zone with sulfides-Miner's Bank vein at top of ridge	0	<0.003	190	0.98	0.03	0.6
PG13c	35 ft zone bleached and softer zone periph to A) w/felsite dike	0	<0.003	978	4.15	0.06	0.69
PG13d	75 ft str prop zone Tap on margins of zone, intense prop to wk sericitic; no plag	0.05	0.01	1020	9.30	0.57	7.08
PG14	dump material on Miner's Bank vein, shaft	0.05	0.01	78	0.80	0.02	5.13
PG15	Wyoming Mine upper dump	0	<0.003	121	0.93	0.02	2.89
PG16	Hoffman qtz vein and QSP Tbb with pyrite	0	<0.003	652	4.37	0.23	3.03
PG22	mix of QSP Tap and vein material from Miner's Bank dump (prospect)	0.02	<0.003	237	3.53	0.03	1.34
PG23	qtz vein, Flower of San Juan, moslty quartz, trace pyrite	0	<0.003	<20	0.86	0.02	0.61
PG24	vein and altered wallrock; unamed vein east of Emperor Wilhelm	0.02	<0.003	461	4.87	0.03	1.75
PG25	bleached WSP altered Tbb adjacent to vein with some dissem pyrite	0.02	<0.003	948	8.49	0.04	2.4
PG27	WSP- altered and bleached Tbb 6 ft zone next to Flower of San Juan vein	0.02	<0.003	856	9.03	0.06	2.86
PG28	chloritic altered Tsh (strong prop) near shaft, trace pyrite?, minor calcite, no stable plagioclase	5.41	0.65	1020	7.49	2.42	7.21
PG29	Hough dump, WS wallrock 7-10% dissem py, hily silic replacement ore, w/massive py	0.02	<0.003	656	2.84	0.05	3.28
PG30	propylitic-altered Tap near Tsh contact, mafics to chlor-illite, plagioclase still stable; major calcite	5.95	0.72	632	7.44	2.67	4.42

Table 1. cont'd

Field No.	K %	MG %	NA %	P %	TI %	MN PPM	AG PPM	AS PPM	AU PPM	BA PPM	BE PPM	BI PPM	CD PPM	CO PPM	CR PPM
PG1	4.23	0.12	0.09	0.09	0.18	45	<2	124	<8	653	1	<50	<2	<2	<2
PG4a	3.85	0.04	2.39	0.01	0.06	235	<2	<10	<8	300	9	<50	<2	<2	<2
PG4b	5.26	0.05	2.17	0.01	0.07	127	<2	<10	<8	274	8	<50	<2	<2	<2
PG5	1.83	0.22	0.03	0.03	0.20	114	184	449	<8	176	1	<50	<2	4	3
PG6	6.07	0.19	0.14	0.02	0.21	72	<2	26	<8	1280	1	<50	<2	<2	3
PG8	1.15	0.09	0.02	0.01	0.08	48	891	323	<8	72	<1	<50	6	8	7
PG9	0.63	0.09	0.02	0.01	0.07	27	532	255	<8	35	<1	<50	27	7	5
PG10	0.04	<0.005	0.02	0.05	0.02	11	5	107	<8	102	<1	<50	<2	<2	<2
PG11	2.89	1.22	0.13	0.12	0.46	943	<2	<10	<8	367	2	<50	<2	18	7
PG12	1.97	0.49	0.50	0.07	0.12	457	<2	<10	<8	438	1	<50	<2	5	<2
PG13a	1.21	0.11	0.02	0.02	0.17	46	7	196	<8	239	<1	<50	<2	<2	3
PG13b	0.09	0.01	0.01	0.03	0.04	33	13	95	<8	184	<1	<50	<2	<2	<2
PG13c	1.91	0.20	0.02	0.02	0.18	58	<2	43	<8	204	<1	<50	<2	<2	2
PG13d	3.58	1.11	0.02	0.20	0.66	637	<2	<10	<8	288	2	<50	<2	23	16
PG14	0.31	0.03	0.02	0.01	0.01	135	322	3280	<8	34	<1	<50	501	9	6
PG15	0.37	0.05	0.02	0.02	<0.005	202	869	139	<8	69	<1	<50	299	8	3
PG16	1.84	0.08	0.03	0.13	0.23	83	17	88	<8	707	1	<50	<2	13	5
PG22	3.01	0.08	0.04	0.01	0.19	63	256	526	<8	458	<1	<50	3	4	3
PG23	0.46	0.04	0.02	0.01	0.03	72	29	419	<8	149	1	<50	<2	<2	<2
PG24	4.31	0.25	0.05	0.08	0.15	300	16	6630	<8	920	<1	<50	<2	3	2
PG25	7.23	0.49	0.08	0.05	0.26	128	<2	664	<8	1590	1	<50	<2	3	4
PG27	7.74	0.39	0.10	0.10	0.34	157	<2	74	<8	1560	<1	<50	<2	4	5
PG28	3.30	2.29	0.03	0.15	0.64	1060	<2	10	<8	433	<1	<50	2	25	11
PG29	1.17	0.15	0.01	0.06	0.20	66	75	1770	<8	92	<1	159	<2	9	8
PG30	0.57	1.26	4.40	0.18	0.47	661	<2	19	<8	204	<1	<50	<2	16	12

Table 1. cont'd

Field No.	CU PPM	MO PPM	NB PPM	ND PPM	NI PPM	PB PPM	SR PPM	ZN PPM
PG1	6	<2	10	23	<3	9	43	9
PG4a	3	2	40	12	<3	18	36	23
PG4b	3	3	38	13	<3	23	35	31
PG5	794	4	<4	10	<3	614	114	81
PG6	6	<2	15	21	<3	7	81	10
PG8	414	99	7	11	<3	2320	30	746
PG9	211	316	4	<9	4	3820	19	4320
PG10	223	2	<4	16	<3	203	351	21
PG11	46	<2	20	36	11	20	166	117
PG12	7	<2	8	20	<3	6	128	36
PG13a	8	14	6	15	<3	31	56	7
PG13b	10	104	<4	<9	<3	610	79	8
PG13c	3	<2	8	20	<3	19	31	18
PG13d	57	<2	26	40	16	17	22	114
PG14	1310	21	4	<9	<3	57100	14	96200
PG15	12600	28	<4	<9	<3	31000	15	57700
PG16	347	5	8	30	7	2600	162	108
PG22	230	85	6	18	<3	1020	51	774
PG23	3	77	<4	<9	<3	40	19	17
PG24	9	12	<4	16	<3	20	94	16
PG25	11	<2	13	28	<3	28	102	38
PG27	9	<2	14	28	<3	13	90	24
PG28	65	<2	21	35	15	13	84	109
PG29	3880	28	10	10	7	179	276	42
PG30	123	<2	11	37	10	12	493	77

Table 2. Geochemical data by ICP-AES for composite dump samples (<2 mm) from the Palmetto Gulch area. Leachate analyses as shown in Table 3 were perfomed on splits of these composite samples.

Field No.	Sample Description	AL %	CA %	FE %	K %	MG %	NA %	P %	TI %	MN PPM	AG PPM	AS PPM	AU PPM	BA PPM
PG01WUD	WYOMING MINE UPPER DUMP	9.43	0.05	1.65	4.45	0.61	0.05	0.04	0.23	161	238	88	<8	534
PG01WLD	WYOMING MINE LOWER DUMP	8.23	0.07	2.65	4.12	0.56	0.06	0.09	0.20	246	71	133	<8	527
PG01UP	ROY PRAY MINE DUMP	7.46	0.27	5.91	4.17	0.37	0.06	0.12	0.30	595	24	418	<8	532
PG01LPAD	LOWER PALMETTO MINE ADIT DUMP	8.78	0.19	5.83	4.31	0.51	0.10	0.16	0.40	354	27	1090	<8	499
PG01LPMS	LOWER PALMETTO MINE SHAFT DUMP	8.04	0.28	4.82	4.18	0.47	0.06	0.13	0.39	257	111	760	<8	785

Field No.	cont'd	BE PPM	BI PPM	CD PPM	CO PPM	CR PPM	CU PPM	MO PPM	NB PPM	ND PPM	NI PPM	PB PPM	SR PPM	ZN PPM
PG01WUD	WYOMING MINE UPPER DUMP	2	<50	25	3	5	46	23	11	28	<3	2870	68	4180
PG01WLD	WYOMING MINE LOWER DUMP	1	<50	7	3	6	42	49	9	22	<3	1450	39	1290
PG01UP	ROY PRAY MINE DUMP	<1	<50	12	4	15	281	16	18	32	<3	2300	71	1700
PG01LPAD	LOWER PALMETTO MINE ADIT DUMP	1	<50	<2	5	11	67	120	21	33	<3	741	83	319
PG01LPMS	LOWER PALMETTO MINE SHAFT DUMP	<1	<50	<2	3	15	71	251	18	32	<3	1190	72	179

Table 3. Xray diffraction data for rock and mineralized samples showing relative abundances of each phase. nd, not determined.
WSP=weak sericitic; QSP=quatz-sericite-pyrite; AS=acid-sulfate; HPROP=hdrothermal propylitic; Dump=grab sample from dump.

Field No.	Sample Despcription	assemblage	quartz %	intensity 20.8 2-theta qtz	quartz
PG1	bleached and weak sericitic-altered Tf	WSP	nd	3197	major
PG4a	very weakly altered rhyolite dike	WSP	nd	2439	major
PG4b	sericitic altered margins of rhyolite dike, no sanidine	QSP	nd	4032	major
PG5	WSP-altered zone adjacent to rhyolite dike on Hoffman vein; k-feldspar stable	WSP	nd	2156	major
PG6	bleached and weak sericitic-altered Tf	WSP	nd	2801	major
PG8	grab dump material from lower Palmetto adit	Dump	nd	4857	major
PG9	grab dump material from lower Palmetto shaft	Dump	nd	5570	major
PG10	highly altered and silicified Tf with dickite, minor pyrophyllite, and svanbergite cut by qtz veins	AS	82	6173	major
PG11	strongly propylitized Tsh, major calcite, no stable feldspar	HPROP	nd	1557	major
PG12	green propyltized Tsh, stable plagioclase, metastable biotite, minor calcite	HPROP	nd	3976	major
PG13a	35 ft wide QSP zone adjacent veinTap	Vein Alt (QSP)	nd	5615	major
PG13b	15-20 ft vein zone with sulfides-Miner's Bank vein at top of ridge	Vein	nd	6180	major
PG13c	35 ft zone bleached and softer zone periph to A) w/felsite dike	WSP	nd	3966	major
PG13d	75 ft str prop zone Tap on margins of zone, intense prop to wk sericitic; no plag	HPROP	nd	1407	major
PG14	dump material on Miner's Bank vein, shaft	Dump	nd	7770	major
PG15	Wyoming Mine upper dump	Dump	nd	4203	major
PG16	Hoffman horn qtz vein and QSP-altered Tbb with fine-grained pyrite	QSP/Vein	nd	3960	major
PG22	mix of QSP Tap and vein material from Miner's Bank dump (prospect)	QSP/Vein	nd	10569	major
PG23	qtz vein, Flower of San Juan, moslty quartz, trace pyrite	Vein	nd	7600	major
PG24	vein and altered wallrock; unamed vein east of Emperor Wilhelm	Vein/WSP	nd	3542	major
PG25	bleached WSPP altered Tbb adjacent to vein with some dissem pyrite	WSP	nd	1750	major
PG27	WSP- altered and bleached Tbb 6 ft zone next to Flower of San Juan vein	WSP	nd	1447	major
PG28	chloritic altered Tsh (strong prop) near shaft, trace pyrite, minor calcite, no stable plagioclase	HPROP	nd	1378	major
PG30	propylitic-altered Tap near Tsh contact, plagioclase still stable; major calcite	HPROP	nd	1500	major

Table 3. cont'd

Field No.	plagioclase	kspar	biotite	chlorite	kaolinite	dickite	pyrophyllite	alunite	svanbergite	calcite	sericite 1M	sericite 2M1	illite-1MD
PG1		v-major									major		
PG4a		v-major/san									minor		
PG4b											major		
PG5		v-major									trace		
PG6		v-major									major		
PG8											major	minor	
PG9											major		
PG10						major(18%)			trace				
PG11				major						major	major		
PG12	minor		major	minor						minor	major		
PG13a											minor	trace	
PG13b						minor	trace	?					
PG13c											major		
PG13d				major							major		
PG14													
PG15											minor		
PG16											major		
PG22		major									minor		
PG23											minor	minor	
PG24		major	?		minor-trace						major		
PG25		v-major									major		
PG27		v-major			minor						major		
PG28				major						minor	major		
PG30	v-major			major						major			trace

Table 3. cont'd

Field No.	jarosite	pyrite	rutile	anatase	galena	sphalerite	tetrahedrite	chalcopyrite	hydrocerussite
PG1									
PG4a									
PG4b		minor		trace					
PG5									
PG6									
PG8		major			minor?	major	minor		
PG9		major			major	major	trace?		
PG10		<1%							
PG11			trace						
PG12									
PG13a		minor		minor					
PG13b	minor								
PG13c				minor					
PG13d				trace					
PG14		minor			minor	major			trace
PG15		minor	trace		major	major		major	
PG16		major		trace					
PG22	trace	minor							
PG23		trace	trace						
PG24	trace								
PG25		minor		trace					
PG27	trace?								
PG28		trace?	trace						
PG30		?							

Table 4. Leachate analyses (ICP-MS) of select mine dumps in the Palmetto Gulch area. Following procedures of Hageman and Briggs (2000).

Sample ID	Dump Locality	pH	Cond	SO_4	Ag	Al	As	Bi	Cd	Cu	Fe	Mg
5 minute static leach test			μs/cm	mg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
PG01LPMS5	Lower Palmetto-shaft area	3.54	345	95	< 3	474.0	9.8	< 0.005	4.17	150.0	141	710
PG01LPAD5	Lower Palmetto-small adit dump	3.85	88	12	< 3	34.8	3.8	< 0.005	0.27	19.2	< 50	170
PG01UP5	Upper Palmetto-Roy Pray cross-cut	3.07	800	234	< 3	8,340.0	45.5	< 0.005	86.20	1,150.0	3,870	6,230
PG01WLD5	Wyoming-lower dump	3.84	77	9	< 3	6.3	3.7	< 0.005	0.73	8.2	< 50	20
PG01WUD5	Wyoming-upper dump	3.37	229	28	10.40	71.8	11.8	0.06	9.62	57.1	496	100
												0
EPA 18 hr leach test												0
PG01LPMS18	Lower Palmetto-shaft area	3.5	400	111	< 3	902.0	9.5	< 0.005	5.13	181.0	166	920
PG01LPAD18	Lower Palmetto-small adit dump	3.72	125	22	< 3	206.0	4.0	< 0.005	0.84	52.6	< 50	510
PG01UP18	Upper Palmetto-Roy Pray cross-cut	2.92	939	146	< 3	4,260.0	18.7	< 0.005	52.60	606.0	1,810	2,950
PG01WLD18	Wyoming-lower dump	3.63	132	14	< 3	55.7	1.0	0.05	4.76	45.1	117	120
PG01WUD18	Wyoming-upper dump	3.24	298	42	36.70	289.0	5.1	0.06	21.60	108.0	595	240

Table 4. cont'd

Sample ID	Mn	Mo	Pb	Sb	Se	U	Zn
5 minute static leach test	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
PG01LPMS5	485	1.51	0.40	3.67	< 1	0.40	521
PG01LPAD5	54	0.42	0.20	2.09	< 1	0.05	124
PG01UP5	8,740	0.60	7.90	0.57	< 1	1.29	15,500
PG01WLD5	9	0.22	41.40	20.80	< 1	0.01	202
PG01WUD5	23	0.25	729.00	60.40	< 1	0.03	1,840
EPA 18 hr leach test							
PG01LPMS18	779	1.63	0.64	3.21	< 1	0.56	688
PG01LPAD18	198	0.57	2.80	1.98	< 1	0.14	199
PG01UP18	4,900	0.20	36.70	0.77	< 1	0.86	8,740
PG01WLD18	96	< 0.2	1,050.00	9.69	< 1	0.04	904
PG01WUD18	59	< 0.2	8,330.00	26.20	< 1	0.06	4,260

Table 5. Reconnaissance water quality data from Palmetto Gulch area.

Site	Longitude	Latitude	Altitude	Description	Date	pH	SC, uS/cm	T, °C	DO, mg/L	DO_{sat}, mg/L	Q_{est}, ft^3/sec	Remarks
WPalm1	-107.582127	37.973552	12,620	North Palmetto below Hough	9/28/1999	3.72	1,690	1.1	13.2	14.2	0.005	
WPalm2	-107.580238	37.974211	12,560	Spring east of Hough	9/28/1999	7.15	220	1.4			0.001	No visual evidence of mining impact
WPalm3	-107.581028	37.974307	12,520	Spring east of Hough	9/28/1999	7.55	780	2.9			0.001	No visual evidence of mining impact
WPalm4	-107.581127	37.974588	12,520	Trib below Engineer Pass (mining-affected?)	9/28/1999	4.65	440	1.8			0.15	White precips blw mixing zone
WPalm5	-107.579433	37.976239	12,440	Spring from bedded Tsh	9/28/1999	6.78	110	1.4			0.001	No visual evidence of mining impact
WPalm6	-107.578767	37.976009	12,420	Bigl big spring from intrusive (green xtals)	9/28/1999	7.32	242	2.1	12	15.2	0.05	
WPalm7	-107.578995	37.976286	12,420	North Palmetto Gulch above spring at Palm6	9/28/1999	6.63	268	1.9			0.2	
WPalm8	-107.576073	37.977698	12,380	North Palm. G. below Engineer Pass road	9/28/1999	6.9	280	3.6			0.5	
WPalm9	-107.575581	37.977059	12,380	Spring on trail	9/28/1999	6.96	232	3.3			0.001	No visual evidence of mining impact
WPalm10	-107.574743	37.970263	12,620	Wyoming Mine, drainage tunnel below shaft	9/28/1999	6.21	198	3.6	7.1	13.8	0.02	Large mine workings area, blw cirque basin
WPalm11	-107.575197	37.972735	12,360	Spring south of BLM mine	9/28/1999	5.45	120	3.1	12.4	13.7	0.01	Moss, algae
WPalm12	-107.574994	37.973079	12,320	Spring near confluence w/ middle Palm. G.	9/28/1999	6.57	130	5.5			0.01	Across (south) from BLM mine dump
WPalm13	-107.574506	37.973444	12,320	Drainage from workings of BLM mine	9/28/1999	3.21	1,525	6.9			0.04	Kill zone, red precips
WPalm14	-107.573656	37.973721	12,320	Middle Palm. G. below BLM mine	9/28/1999	3.93	600	5.7			0.3	Red/orange precips
WPalm15	-107.574912	37.973380	12,360	BLM mine drainage	9/28/1999	3.34	1,775	2.7	12.2	15.1	0.01	Bright orange precips
WPalm16	-107.574385	37.973400	12,360	Seep adjacent to adit	9/28/1999	5.97	370	9.5			0.001	
WPalm17	-107.576278	37.972966	12,460	Red spring in canyon abv BLM mine	9/28/1999	3.29	1,120	2.6			0.002	Some mixed drainage from shafts that worked vein structure
WPalm18	-107.577050	37.973063	12,500	Middle Palm. G. upstream from 17	9/28/1999	5.4	338	5			0.2	White precips, natural above here except for small shaft (site 21)
WPalm19	-107.577388	37.973013	12,520	Spring in canyon above 18	9/28/1999	6.7	172	6			0.002	No visual evidence of mining impact
WPalm20	-107.578299	37.972255	12,550	Middle Palm G. below peat fan	9/28/1999	5.62	315	7			0.15	White precips
WPalm21	-107.580889	37.971875	12,620	Water in shaft in drainage above peat fan	9/28/1999	6.08	405	2.2				Water level 3 ft below surface
WPalm22	-107.581345	37.972158	12,640	Upper Middle Palm. G. above mines	9/28/1999	6.78	200	5			0.05	
WPalm23	-107.566185	37.979810	11,680	Palm. G. below confluence of upper 3 tribs	9/30/1999	4.23	345	2.9	9.1		1.5	White precips
WPalm24	-107.567600	37.979497	11,720	North trib Palm. Guch near confluence	9/30/1999	3.86	226	5.9			0.5	
WPalm25	-107.567774	37.978804	11,720	South trib Palm. Gulch near confluence	9/30/1999	3.68	440	1.1			1.0	White precips
WPalm26	-107.567679	37.978351	11,800	Spring near confluence	9/30/1999	3.92	282	5.7			0.005	No visual evidence of mining impact; along FSJ vein
WPalm27	-107.569481	37.976498	11,980	Big spring in fractured rocks	9/30/1999	3.97	175	2.6			0.01	
WPalm28	-107.569707	37.976880	12,000	Middle Palm. G. below BLM mine	9/30/1999	3.85	545	3			0.75	Red/orange precips, lots of water comes in between
WPalm29	-107.568827	37.975503	12,020	South trib PalmG	9/30/1999	3.96	300	6			0.25	No precips
WPalm30	-107.570491	37.973163	12,160	South Palm G. above vein structure	9/30/1999	3.94	332	4.1			0.25	
WPalm31	-107.570959	37.973237	12,160	Trib from Wyoming at South Palmetto Gulch	9/30/1999	3.81	252	8.3			0.08	
WPalm32	-107.573138	37.972493	12,420	Wyoming trib below cliffs (the "red streak")	9/30/1999	3.96	360	1.8				Water mostly in the subsurface, sampled drips
WPalm33	-107.572222	37.972341	12,480	Mine pool, yellow precipitates	9/30/1999	4.03	565	2			0.001	Drips enter mine 100 ft from entrance
WPalm34	-107.571909	37.970258	12,460	Spring draining grey rocks	9/30/1999	5.25	242	5.5	5.1	6.8	0.002	No visual evidence of mining impact
WPalm35	-107.571945	37.969733	12,520	Possible drainage from uppermost prospects,	9/30/1999	4.42	182	3.7	5.2	6.5	0.001	Red precips, could be spring
WPalm36	-107.573204	37.969277	12,540	Source spring of South Palm. Gulch	9/30/1999	4.43	220	7.5			0.003	Uncertain if mining-impacted
WPalm37	-107.572770	37.967624	12,640	Spring along vein structure above mines	9/30/1999	4.05	185	5.3			0.001	No visual evidence of mining impact
WPalm38	-107.572770	37.967624	12,700	Spring below cirque basin	9/30/1999	4.16	240	10.5			0.002	No visual evidence of mining impact, red white precips
WPalm39	-107.571888	37.970669	12,400	Big spring, see discussion in text	9/30/1999	4.19	195	8.1			0.05	Blue/white precips blw confl w/ red mainstem,
WPalm40	-107.571001	37.970846	12,400	Big spring, see discussion in text	9/30/1999	4.01	535	5.4			0.05	
WPalm41	-107.570858	37.971288	12,390	South Palmetto Gulch	9/30/1999	4.15	328	7.1			0.1	Blue/white precips, stream clears up way before